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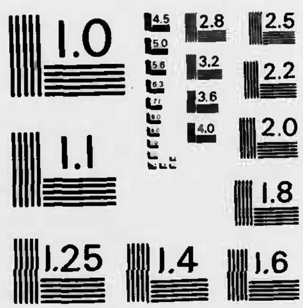

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In September of 1982, the Defense Mapping Agency Hydrographic/Topographic Center printed and released to the public a Standard Nautical Chart which was compiled, symbolized, and color separated using computer technology. The production of this chart involved several different computer driven mapping systems, as well as a unique mix of cartographers and computer specialists. This report describes the methodology, techniques, and computer systems used to produce the chart.

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Automated Standard Nautical Chart Production

by

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Washington, D.C. 20305

Abstract

In September of 1982, the Defense Mapping Agency ~~Hydrographic/Topographic Center~~ printed and released to the public a Standard Nautical Chart which was compiled, symbolized, and color separated using computer technology. The production of this chart involved several different computer driven mapping systems, as well as a unique mix of cartographers and computer specialists. This report describes the methodology, techniques, and computer systems used to produce the chart.

Introduction

In September 1982 the Defense Mapping Agency (DMA) released for sale to the public, chart 62097, Approaches to Bandar at Tawahi. The publication of this chart represented a milestone in the Defense Mapping Agency's continuing efforts to develop more efficient production procedures for its standard nautical charts.

The compilation of a standard nautical chart using conventional techniques normally involves a series of labor intensive, manual steps. Generally speaking, a cartographer will select information from various hydrographic and topographic sources for portrayal on a chart. This information is 'pulled-up' on a series of overlays, which are then mosaicked to fit a final scale, transformation, and datum, forming a compilation manuscript. The manuscript is then symbolized through scribing or drafting operations.

In the compilation of chart 62097, these same tasks were accomplished; but automated cartographic techniques and methodologies were employed, instead of the manual procedures outlined above. In addition, a set of constraints and objectives were established to ensure that a chart produced in this manner would be as accurate and cartographically correct as those compiled conventionally. These constraints and objectives are listed below.

Constraints

The automated chart production system was to utilize only equipment currently in operation.

Product integrity and accuracy were not to be sacrificed for increased savings and throughput times.

Objectives

Compile a nautical chart utilizing automated means to the fullest extent possible.

Determine the optimal utilization of equipment and manpower.

Assess the advantages and disadvantages of the automated chart production system developed.

Minimize throughput times and maximize savings while maintaining product integrity.

The following discussion describes the techniques and methodologies, as well as the equipment, used to compile chart 62097.

Current Technology and Compilation Requirements

An analysis of the source documents used in the compilation of a nautical chart would reveal that they basically fall into two categories: those used primarily for hydrographic information, and those used mainly for topographic data (see Figure l. for chart 62097 sources). Closer analysis would reveal that the information selected from a hydrographic source for use in a chart is preponderantly point features, (soundings, aids to navigation, etc); while topographic information is primarily linear in nature. This distinction was a key factor in determining how to optimize the use of automated cartographic technology in the chart compilation procedure.

The automated cartographic equipment existing at the DMA today is either raster or vector in nature with regard to their data storage, manipulation, and capture capabilities. Each of these technologies have relative advantages and disadvantages in their use.

Raster scanning technology is extremely efficient in the mass digitization of source documents containing medium to dense line work. Using raster scanning methods, sources meeting these requirements can be digitized in a quick and efficient manner. This method of data capture does have one significant drawback however, the raster information cannot be assigned any attributable information (i.e., a bathymetric contour cannot be assigned a depth value). Without this information, the collected data would not be very useful in the compilation procedure, and could not be part of an integrated chart data base. Thus, to reap the benefits of mass digitization, the raster scanned data must be converted to vector mode; a data format which permits the assignment of descriptive information to digitized data. The cartographer, by manipulating data in this fashion avoids the tedious and time consuming chore of manually collecting this data with a hand held digitizer.

As mentioned earlier, data in vector format has the advantage of permitting 'tagging'. This format is also advantageous because it requires less storage space than the raster format, and is more efficiently manipulated especially with regard to compilation functions. Such operations as projection transformation, scale change, mosaicking, merging, sounding unit conversions and general distortion removal are more easily and efficiently accomplished with data in vector format.

One additional capability must be discussed regarding vector based technology; the capture, tagging, and processing of point feature data. To incorporate a point feature into a vector file, a cartographer must build a header describing that feature, 'visit' its location, and digitize its position and attribute information. While this procedure may seem relatively inefficient especially with regard to the mass digitization of linear features, there is currently no existing 'automated' alternative at DMA within the nautical chart program.

Given the relative merits of each of the two technologies, as well as the differences between hydrographic and topographic feature types the decision to maximize the use of DMA's automated cartographic equipment in the chart compilation process was clear cut. A raster based system, the Sci-Tex Response 250 Mapping System, was utilized in the mass digitization/vectorization of topographic sources. The Advanced Cartographic Data Digitizing System (ACDDS), a vector system, was used to collect the hydrographic data and perform chart compilation tasks.

Equipment Descriptions

ADVANCED CARTOGRAPHIC DATA DIGITIZING SYSTEM (ACDDS)

The ACDDS is a vector formatted digitization and compilation system. It consists of a host subsystem and four (4) independent workstations.

The ACDDS was developed for DMA by the Synectics Corporation. The system hardware was designed to be redundant so if any part of the system fails, the rest of the system can continue operation.

System Procedures - Analog data, including survey sheets, maps, U.S. charts, foreign charts and other manuscripts, are digitized on the digitizing table and stored on the workstations disk at their original scale and projection. The data are digitized in one of three modes: trace, depth (soundings), or point feature. As each feature is digitized, it is displayed on the graphics CRT for verification by the cartographer. At any point in this digitizing process the cartographer has available a full range of interactive edit functions to modify any feature in the file.

When this data is correct the cartographer can transfer the data to the host system to perform any of the following batch functions:

1. Projection transformations including datum shifts and scale changes.

2. Sectioning - data inside a cartographer-defined area are extracted and put into a separate file.

3. Merging and paneling - several files are merged into one file.

4. Sorting (filtering) - feature types defined by the cartographer are extracted and put into another file.

5. Unit conversion - the units of measure of soundings are converted to other units of measure (i.e. fathoms and feet to meters).

6. Proof plotting - either symbolized or centerline data depiction.

7. Magnetic tape input and output.

The information collected from various sources at the edit station are combined into one master file of the same scale and projection type through host operations. This file can then be returned to the edit station for additional interactive edits and refinements. Such edits include the addition of any new data (ie., Notice to Mariners), the correction of any overprinting information, and the improvement of the aesthetic qualities of the chart.

When the data is fully edited and in final form the cartographer can send the file to the host system where fully symbolized and color separated CRT plotter tapes can be generated. These tapes will drive the plotter to produce reproducible quality film positives.

THE CRT PRINTHEAD PLOTTER

The CRT Printhead is a very high speed, vector formatted plotter capable of producing reproducible quality film positives. This system was developed for DMA by Image Graphic Inc. It allows dense vector formatted data to be plotted at a speed equal to or greater than raster plotters. Data are sorted into 2" x 2" pages before plotting to minimize the mechanical movement of the plotter. When the CRT printhead plotter receives this sorted data, it moves the printhead to each "page" and flashes all of the data within that 2" x 2" area. This procedure greatly reduces the time consuming mechanical movement characteristic of conventional vector plotters.

The CRT plotter can also virtually store an unlimited number of reproducible quality symbols on its software disks, thereby making point symbol and type placement economical.

THE SCI-TEX RESPONSE 250 MAPPING SYSTEM

The SCI-TEX Response 250 Mapping System (R250 MS) is a color, raster/graphic editing system with a scanner, edit station, and film exposure device (a laser plotter). The flow of data through the system is from scanner (data capture) to edit station (color separation corrections and cartographic updates), then to laser plotter (color separated film output).

The SCI-TEX Response 250 Mapping System was acquired "off the shelf" in late 1978/early 1979. The configuration of the system at DMAHTC currently consists of one scanner, 4 edit stations, and one film exposing device (a laser plotter).

System Procedures - Analog data including survey sheets, maps, U.S. charts, foreign charts and other manuscripts are mass digitized via a 12 color raster scanner. Data are stored on edit station disks as functions of x, y position and color. These data can be scanned at various resolutions (4 - 47 points per millimeter) accessed and displayed at the edit station.

Depending upon the nature of the final product (i.e., color separation, resymbolization, etc), the following edits may be utilized:

a. Raster/Vector/Raster data conversions - Linear data captured via the scanner in raster mode can be converted to vector mode, tagged with a symbolized feature type such as a built-up area boundary and converted back to raster as fully symbolized data.

b. Point feature symbolization - Point feature data can be symbolized by calling various symbolized point features from a previously defined library and inserting them into a file at a desired x, y location, at any rotation. The insertion of symbols into the raster data can be accomplished interactively, manually, or automatically.

c. Area Feature Symbolization - Area outlines can be defined interactively or acquired via the scanner. The areas defined by these outlines can be filled with a solid color (thereby producing an open window of the area) or a symbol can be repeated throughout the area (i.e. a marshland symbol could be repeated across a polygon producing a marshland areal symbol).

d. Color Separation Editing - Scanned data inevitably contains data which has been incorrectly sensed and color coded (i.e. dark blue data sensed and coded as a light blue). These areas or islands of incorrectly color coded data can be recoded to their correct color via interactive or global (file wide) editing functions.

e. Type Composition and Placement - Typed in various fonts and point sizes can be composed and interactively placed into a data file. Currently the DMAHTC R250OMS font Library consists of the following type styles and point sizes:

1. News Gothic Condensed - 6 and 7 point
2. News Gothic - 6,7,8,10,12,14,16,18 and 30 point
3. Techno Medium - 6,7,8,10,12 and 14 point
4. Techno Medium Italic - 6,7,8,10,12 and 14 point
5. Century Expanded - 6,7,8,10,12 and 14 point
6. Century Expanded Italic - 6,7,8,10,12 and 14 point

When the data are fully edited and in final form the cartographer can output his data file as color separated film negatives or positives via the laser plotter.

Compilation Procedures

TOPOGRAPHY (see figure 2)

The topographic sources used in the compilation of Chart 62097 were photogrammetrically derived manuscripts, compiled on the AS11A stereo compilation instrument. The AS11A through interior, relative, and absolute-orientation of stereo imagery was used to remove film and model distortions (tilt, parallex, etc.) from the photographic coverage of Aden Harbor. The photogrammetrist then utilized this stereo imagery to extract significant topographic features. These data were compiled at the final scale and projection of the chart. Additional features necessary for hydrographic/navigation requirements were then added to these manuscripts through a landmass intensification procedure.

The linear data depicted on any topographic source can be classified in several ways. These data can be classed according to the information they represent (i.e., a road vs. a railroad), or the manner in which they are depicted on the document (double line symbol (road) vs. a ticked line (railroad)). To facilitate the mass digitization and subsequent symbolization of the topographic manuscript, the compiled linear features were classed by the latter method. This classification was accomplished through the use of several different colors as data depiction mediums.

For example those features that were to be symbolized (on the final chart) as solid lines with a lineweight of 8 mils (shoreline and drainage) were depicted as centerline information in the color red, while those requiring cased or paralleled line symbolization were drawn as centerline information in the color green. The net result of these actions was a symbol classification manuscript that facilitated the symbolization of topographic information.

The manuscript was mass digitized (scanned) on the Sci-Tex scanner at a resolution of 10 points per millimeter (x0.004 mils). The scan required 7 colors, 6 for the color coded information, and one channel for the background color. Upon completion of the scan, the resulting data (in raster format) were checked and corrected for minor dimensional inaccuracies. Following this procedure, the scanned information was examined (at the edit station) for any improperly color coded data induced by the scanner.

As a necessary step to achieve the conversion of the data to vector format, a skeletonization operation was initiated. This function automatically delineated the center or midline of each feature. These skeletonized data were then edited for unintended gaps and spurious data (i.e., spikes generated by skeletonization). With these edits complete, the topographic information was ready for vectorization.

The program which initiates the conversion of skeletonized data to vector strings requires that the operator assign a symbol tag to the information to be vectorized. It is at this juncture that the color coding of topographic linework comes into play. By guaranteeing that those features coded in a given color are to be symbolized identically on the chart, we can automatically tag each feature within a classification with the same symbol tag. So when the vector data is rasterized again, the correct reproduction quality symbology has replaced the original pencil compilation.

The photogrammetric manuscript contained a limited number of point features which were interactively symbolized via the Sci-Tex. By utilizing a predefined symbol file and visiting each point feature, the appropriate symbol was incorporated into the data (i.e. a rock awash or building symbol).

HYDROGRAPHY (See Figure 3)

The film positive generated on the Sci-Tex served as the controlling source for the compilation of hydrography on the ACDDS. All 5 hydrographic sources used in the compilation were controlled through shoreline matches to the Sci-Tex, topographic positive.

Each piece of hydrographic source material was registered to an ACDDS digitizing table and features selected by the cartographer were digitized at the

scale, unit of measure and projection of the source document. This digitization was done by selecting a header for each feature, entering a depth or elevation if necessary, and manually digitizing each feature with a cursor. As these data were digitized they were displayed on the system's graphic CRT to allow the cartographer to verify these data and view their spatial relationship to other information. The digital file of each source was then plotted on the Xynetics proof plotter. This plot was then compared with the original source document to verify the accuracy and completeness of the digital file. If data in any of the source files were found to be incorrect or missing the file was then corrected interactively by the cartographer on the ACDDS workstation.

Some of the sources used for chart 62097 had soundings measured in fathoms and feet rather than meters. Since U.S. Chart specifications require all soundings to be shown in meters, the sounding features of these sources were converted to meters automatically by the ACDDS. This eliminated the labor intensive effort of using a table to look up the meter value of each sounding. It also eliminated the possibility of human error during the conversion process.

Following these operations, the digital file of each source was mathematically transformed by the ACDDS to the projection, scale and spheroid of the final product, and then digitally mosaicked to the shoreline of the Sci-Tex symbolized positive and/or other hydrography. This was accomplished by sectioning each source file, shifting the data of that section to fit the controlling source and then merging all of these sections into one master file.

After all of the sources were merged into one file, a proof plot was generated to allow the cartographer to determine what corrections, additions, and/or modifications had to be made. The data file was then interactively modified at an ACDDS workstation on a feature by feature basis. This modification process may include:

Joining (connecting) lines
Smoothing lines
Modifying segments to avoid overprints of data
Deleting unnecessary data
Adding newly acquired data (i.e. Notice to Mariners corrections)
Other feature modifications necessary to make the final product more useful and aesthetically pleasing.

When the cartographer was satisfied with his completed compilation, a CRT Printhead plot tape was generated. Since each feature was tagged with attribute information as it was digitized, the plot tape generated contained the necessary instructions to direct the CRT Plotter in symbolizing each feature. The actual film positive production time on the CRT was significantly less than with conventional line following plotters, due to the exposure of 2" by 2" windows of data at the same time.

Type Generation and Placement

Following the completion of the hydrographic compilation phase of the production chart 62097, a type guide was prepared upon which was depicted the

approximate location for a string of text, its point size and font type. This guide (prepared on a proof plot of the hydrographic data) was then scanned on the Sci-Tex and merged with the previously symbolized topography. This file served as a reference pattern relative to which strings of text could be interactively placed on the Sci-Tex Edit Stations.

At the system's prompting, the cartographer was requested to key in the text needed (up to 99 words in a pass). These strings were then automatically composed and placed into a file that was accessed for interactive placement. Utilizing the data file of the merged type guide/topography as a reference pattern and a duplicate file of the previously generated symbolized topography as an output file, the cartographer proceeded to interactively place the text. When deemed necessary, a paper verification plot was generated for edit purposes. The cartographer would note on this plot any missing text, misspelled words, lines that needed to be broken, or text that needed to be placed in a new position. When all the corrections were completed, final color separated film positives of the text and topography were generated, and a data tape generated for future use.

Open Window and Area Symbolization

A Xynetics plot was generated on the ACDDS of bathymetric contour data, coral, dangers, and uncovering area. A color dot was placed into each of the areas requiring open window symbolization; one color for areas of coral and uncovers, and a different color for areas of danger and significant depth (from the shoreline to the 5 meter curve). Where these curves were broken (interrupted) they were closed to ensure that each color dot was surrounded by an uninterrupted polygon. This tint guide was scanned and merged to the existing symbolized topographic data (the land tint, built up area, and saltpans were generated previously during the processing of the manuscript). These data were then checked for accuracy.

Utilizing a color spreading algorithm, the areas enclosed by each polygon were painted 'solid' using the color dot as the active color. The bounding polygon was then deleted, being replaced by the area fill color(s). In this manner islands of color were created that, when viewed as a integral unit, formed the open window tint area symbolization. A verification paper plot of this data was generated and adjustments made where necessary. This edited file was then used to generate open window film negative via the plotter and the data were saved for future use.

The reproduction quality film positives and negatives generated by the CRT Printhead and Sci-Tex plotters were photo composed and processed in the conventional fashion, concluding the compilation and production of chart 62097.

Benefits of the Automated Chart Production System

The ultimate success of any new production procedure is determined by how it compares to the previous system in terms of accuracy, total manhours and associated pipeline days. In the case of the system just described, significant savings in both manhours and pipeline days will be realized in chart production as a result of the system's initial design and future refinements. In addition the accuracy of the resulting chart was equal to or better than those compiled conventionally.

Utilizing this system, a savings of approximately 26% in manhours can be expected for an average chart. This savings will result from the elimination of many tasks previously required during compilation, (i.e. automatic sounding unit conversions), as well as decrease in the number of redundant operations performed by the cartographer.

The production of a chart through conventional procedures normally requires a good deal of support work from branches other than the compiling element. Utilizing the procedures discussed, most of the support activities normally associated with conventional production procedures (type-setting, drafting/scribing, negative engraving, and photographic processing) are either eliminated altogether, or greatly reduced in time. The pipeline time resulting from the movement of the job from work center to work center to perform these support activities will be reduced significantly (approximately 35%). An example is the virtual elimination of the 100 day scribe/draft production step throughout the use of symbolization algorithms and finishing plotters to produce the reproducible quality color separates.

In addition to the economic benefits resulting from the initial compilation of the chart, further savings will accrue as second and third editions of the chart are required. Subsequent to the publication of a nautical chart, a record is kept of those changes occuring in the area of the chart. When the number of the changes exceeds a certain limit, a new edition of that chart is called for. By maintaining the data resulting from the initial compilation of a chart in a digital chart library, new editions of these charts can be easily produced. Utilizing the initial digital data, the required changes can be made through the system and a new set of reproduction quality positives generated. Any subsequent editions of the chart will be produced in a more efficient manner than could otherwise be accomplished; thus leading to additional savings.

System Refinements

During the compilation of 62097, there were certain inefficiencies in the procedures identified. These inefficiencies, specifically, type placement and open window negative generation, were significant enough to warrant a re-examination and correction of the procedures utilized. While they were not remedied soon enough to be useful on the compilation of chart 62097, the corrections are being applied to current production.

The type placement, while accomplished successfully on the Sci-Tex, proved to be a lengthy process in terms of the time needed to prepare the type guide and the incorporation of the type into the file. To correct this problem, a type placement system has been developed for use on the ACDDS. The cartographer using this new software can efficiently position type strings without the need of a type guide, as well as determine the impact a particular string of text has on other data in that area. The actual 'flashing' of the type is done on the CRT Printhead Plotter, avoiding the 'update' time inherent on the Sci-Tex system.

The open window negative generation scenerio was basically a cumbersome procedure, and for this reason not as efficient as could be possible. Under this initial procedure, the cartographer was required to manually create a tint guide. The solution devised for this problem was to create a data link from the ACDDS to the Sci-Tex. This will permit the cartographer to transfer his polygon data

digitally (tape transfer) to the Sci-Tex, where the painting algorithm is used as described earlier.

Finally, a third improvement was made to the system. Software was developed that permits the transfer of vectorized topographic data to the ACDDS from the Sci-Tex (the reverse of the other data link). This transfer will, among other things, permit the entire data file resulting from the production of the chart to be stored in one file.

Conclusion

The publication of standard nautical chart 62097 represents a significant step forward for DMA's hydrographic automated cartography effort. The production of this chart realized the initial objectives of the project without compromising any constraints. As a result, the automated cartographic production of standard nautical charts can be viewed as coming of age at the Defense Mapping Agency.

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